INFLUENCE ON PERFORMANCE OF FEEDING EGG-STRAIN LAYING HENS INCREASING LEVELS OF PHOSPHORUS WITH INCREASING LEVELS OF CALCIUM

by

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INTRODUCTION

The constant genetic improvement of commercial egg laying strains has resulted in questions concerning the adequacy of calcium and phosphorus. The National Research Council (1962, 1966) typifies the modern trend to increase the recommended levels for commercial layers (primarily leghorn strains). In 1962 the NRC recommended 2.25 percent calcium compared to the present recommendation of 2.75 percent calcium for laying rations. Investigators have failed to establish such an increase in the phosphorus levels in diets; therefore, phosphorus has remained constant at 0.60 percent of the total ration.

With the advancement in automatic handling, improvement in high production strains of chickens, and the formulation of more efficient diets, egg breakage has steadily increased in recent years. Because the shell composition of the avian egg contains 95 percent calcium carbonate, researchers have been interested primarily in the mineral calcium and its relationship to egg shell strength.

Most research studies have been concerned with increasing either calcium or phosphorus levels while maintaining the other mineral at a constant level. Results indicated that increasing either or both of these minerals influenced shell rigidity until a specific tolerance level was reached. Conclusions indicated the tolerance level was influenced by the type of system used (cages or floor type operation), but nutritional factors may also have played an important role.

Increases in the egg production potential of commercial flocks has resulted in less attention to the Ca:P ratio of 2:1, thus more attention is needed to feeding birds to meet the nutritional needs of the highest

producers of each commercial strain with reference to specific environments. The combination of higher production, higher energy rations, smaller birds, and declining feed consumption per dozen eggs produced complicates the problem of shell strength. Establishing the major mineral need of commercial chickens in relation to the declining consumption rate of these birds became a problem of increased discussion among experts.

Associated with methods of increasing shell thickness were the debates concerning the accuracy of experimental measurements. Crude methods of measuring shell fracture to the improved measurements of specific gravity of eggs can be used for comparison. Specific gravity is perhaps the most reliable method unless breakage has occurred, also the egg remains intact for sale or additional experimental work.

The decline in feed consumption of smaller birds attributed to increased interest in higher mineral rations for experimental work. This contributes to the decline of egg production on higher calcium and phosphorus diets. This unprofitable result has lessened the use of higher mineral diets for egg production experiments. Commercial feed companies, however, still use fairly high mineral rations (4-6% mineral). Failure of the commercial poultryman to consider his improved stock's requirements which exceed out-dated research findings contributes to the industry's high percentage of breakage.

Because of genetic trends and the demands of a competitive industry, the hen of today has become a "stream-lined" factory, and will become more so in the industry's future. With constant changes and improvements, these specialized strains must be treated more as individuals and their diets formulated for them with consideration to their environment. More

eggs per hen per year result in increased mineral requirements for maintenance and shell quality. The secret of improved shell quality lies with both minerals (calcium and phosphorus) as well as with a high quality ration.

The primary purpose of this investigation was to improve shell quality by increasing dietary levels of calcium and phosphorus. An attempt at feeding various levels of both minerals without adversely affecting egg production, feed efficiency, and various other performance factors was conducted. This investigation was conducted to determine the optimum combination of calcium and phosphorus essential for maximum egg production and shell thickness for the particular strain used (Hyline 934-E).

LITERATURE REVIEW

Various workers have indicated that egg production, egg weight, feed efficiency, and specific gravity of eggs may be influenced by several factors (Arscott et al., 1962; Berg et al., 1950; Edwards and Dunahoo, 1958). These researchers have shown how various environmental factors and diet composition interrelated to influence the results of an experimental study's measurements. An investigation of these factors was conducted with special emphasis on calcium, phosphorus, and influences on specific gravity of eggs.

CALCIUM

RELATIONSHIP OF INGREDIENTS TO CALCIUM

Edwards and Dunahoo (1958) concluded that a high level of dietary

fat (1260 Calories of metabolizable energy) increased the calcium requirements of growing chickens by interfering with calcium absorption. Confirmation of this theory was made by Griffith et al., (1961) using AOAC methods of analysis.

Hurwitz and Bornstein (1966) reasoned that high calcium levels depressed feed consumption at high dietary fat levels, but could find no significant difference upon testing their theory. Using broilers, Pepper and co-workers (1955) found that feed efficiency was increased when higher levels of calcium were used with higher levels of dietary fat. Lower levels of fat did not seem to influence the calcium requirements of these birds.

Studies comparing the role of ascorbic acid and its relationship with calcium metabolism have not given consistent results. Arscott et al., (1962) and Pepper et al., (1961) agreed that increasing the level of calcium does not necessitate a similar increase in ascorbic acid content of the laying ration under normal environmental conditions. Significant improvement in egg shell thickness was recorded by Thornton (1960) at high environmental temperatures with the addition of ascorbic acid to high calcium diets. Sullivan and Kingan (1962) found that specific gravity and shell thickness significantly increased during a year's study comparing rations with and without ascorbic acid. The same results indicated a small but nonsignificant increase in specific gravity and shell thickness with increasing levels of calcium and ascorbic acid.

Ascorbic acid investigations revealed no consistently adverse effects on egg production and egg weight; therefore, definite conclusions could not be developed. Combining ascorbic acid with nutritional additives has

shown increases in egg production and feed efficiency, but those increases were rarely significant (Wilkinson, 1961).

Vitamin D and protein are two other nutrients whose effects have been extensively reviewed by authorities as affecting calcium requirements of laying hens. Titus (1958) conducting several studies on calcium levels in laying rations concluded that the quality of protein affected the level of calcium tolerated by cage layers. His conclusions were based upon experimental data which showed differences between high levels of calcium (4.0-6.0% calcium) on total egg production. Analysis of the rations showed an extreme differences in quality of protein. A similar experiment, maintaining the same level and quality of protein, resulted in no significant difference in levels of calcium (3.0-6.0% calcium), indicating that poor quality protein either decreased or increased the calcium requirements for layers (four strains of New Hampshire layers were used for this experiment). Using specific gravity, egg shell weight, and egg shell weight per unit of surface, Pepper and co-workers (1968) found that addition of fish meal (high quality protein) failed to improve egg shell quality.

Employing four levels of protein (12, 14, 16, and 18%) and using two levels of calcium at 2.4 and 3.0 percent, Pepper _et al._, (1967) found a dietary relationship between dietary protein and calcium for laying hens. At 12 percent protein, significantly fewer and smaller eggs and poorer feed efficiency resulted than at the higher levels of protein. No significant difference was recorded for any of the performance data between the two levels of calcium tested.

Edwards and co-workers (1960) working with the effect of protein, energy, and fat content of the ration on calcium utilization of young

chickens stated that the requirement for dietary calcium increased as feed efficiency increased. This study contained three different protein levels, but the calcium:protein ratio of the ration was the same for all treatments.

Considering the effect of increasing the level of vitamin D and the level of calcium in the laying ration, Berg et al., (1950) found no improvement in shell quality, egg production, or shell smoothness. Increasing the levels of calcium and vitamin D at 84 day intervals also failed to prevent seasonal decline in laying performance. Using growth data for measuring performance, Biely and March (1957) found that increasing the levels of calcium and vitamin D improved bone calcification and broiler growth until the specific tolerance level was reached.

Authorities have previously concluded that source of calcium played an influential role in calcium requirements of layers. Balloun and Marion (1962) found that egg weight, shell surface area, and egg volume were significantly less when calcium lactate was substituted in place of calcium carbonate. They also indicated that egg production for the seven month period was adversely affected by the higher levels of calcium regardless of the source. Their study compared both sources at the 2.25 and 2.75 percent calcium levels. A comparison of two calcites as calcium supplements was conducted by Lillie and Thompson (1947) to determine if differences could be attributed to the kind of calcite. Pure calcite and impure calcite were the sources tested. Upon analyzing the data, no real difference was noted in egg production, feed consumption, egg shell breaking strength, mortality or body weight. The only significant difference occurred in hatchability which was higher for the impure calcite at the 0.01 level of probability.

Heuser and Norris (1946) compared oyster shells, calcite grit, ground limestone, and granite grit as supplements to a laying ration. From their study it was concluded that egg shell strength rated in descending order as follows: Oyster shell, calcite grit, ground limestone, and granite grit. Griminger and Lutz (1964) observed voluntary intake of calcium supplements by layers in individual cages, community cages, and floor pens. Crushed oyster shell and calcite grit were the two calcium supplements investigated. Wastage of the supplements increased with floor pens, and level of dietary calcium profoundly influenced calcium supplement consumption for floor pens but not caged hens.

Methods of supplying calcium have also initiated experiments to determine effects on the performance of laying hens. In a comparison of three methods of supplying calcium, Mehring (1964) concluded that New Hampshire layers would adjust to meet their calcium requirements. During the test hens allowed to adjust their calcium intake to meet their needs produced significantly stronger shells. Upon final analysis, it was determined that all three methods of supplementation were equivalent (Methods: all in the feed, part in the feed and part free choice, and all free choice except that contained in the ingredients).

EFFECTS OF HIGH CALCIUM LEVELS ON PERFORMANCE

Early investigators studying the effects of high calcium rarely included levels above 3.50 percent calcium in the experimental diets (Evans _et al_., 1944; Tyler, 1946). Recent studies, however, have considered dietary calcium levels as high as 6.00 percent of the ration (Hurwitz, 1964; Pepper _et al_., 1968; Titus, 1958). Mehring (1964) recorded information concerning voluntary intake of calcium, indicating

that birds could adjust to meet their calcium requirements.

Titus (1958) studying various levels of calcium (1.0-6.0%) found a highly significant difference in egg production at the higher levels of calcium. Comparing the results of four studies, he concluded that floor layers could tolerate large excesses of calcium, and attributed this ability to the fact that excess absorbed calcium may be excreted largely as dicalcium phosphate or tricalcium phosphate. With each experiment, Titus established the effects of various nutrients (protein, energy, and phosphorus) upon the level of calcium required. In each test the highest level of calcium, with all other factors constant, produced the best production, hatchability, and shell strength in floor layers.

Conducting a test for five months with laying strain pullets, Pepper and co-workers (1968) established that increasing levels of 4.0, 5.0, 6.0 percent calcium increased egg specific gravity as compared to control rations of 3.0 percent calcium. Hurwitz and Bornstein (1966) summarized the effects of high dietary calcium on the performance of layers fed varying levels of dietary energy and found no significant difference when compared to a 3.0 percent calcium diet. Isonitrogenous and isocaloric diets containing calcium levels ranging from 1.0 to 6.0 percent showed increases in shell strength for each increase in calcium with shell strength greatest at the 6.0 percent level (Mehring, 1964). Reviewing research results, Hill (1965) stated that increasing the level up to 6.0 percent did not depress performance criteria for floor layers.

Hinners _et al_., (1963) stated that shell thickness significantly increased as the percentage of calcium increased up to the 5.50 percent calcium level ($P < 0.05$). Hen-day production declined slightly but significantly at levels as high as 6.27 percent calcium. This experiment

was conducted using Single Comb White Leghorn hens beginning after completion of six months of production.

Measuring the effects that environmental temperature had upon higher levels of calcium, Peterson and co-workers (1960) suggested that rations contain 4.0-5.0 percent calcium at temperatures of 70°F. and at less than 70°F. a level of 3.75 percent calcium was recommended. These recommendations were based on the detrimental effect of high temperatures on shell quality. The results of this study indicated that egg production, feed consumption, and pounds of feed required per dozen eggs were not decreased by high levels of calcium.

Reddy and Sanford (1963) concluded that calcium intake between 3.05 and 3.85 percent significantly improved shell quality over higher levels of calcium intake. They obtained maximum egg production at the 3.85 percent level; however, egg production declined at levels higher than 3.85 percent. Results obtained by Titus (1958) showed the 3.00 percent level to be sufficient for needs of laying hens. With caged layers Mehring and Titus (1964) found marked effects on shell strength, live weight, and percentage bone ash comparing low levels of .20 and 1.24 percent calcium to a control of 2.43 percent calcium.

Pepper and associates (1961) found that increasing the level of calcium decreased egg weight loss and increased egg specific gravity in a highly significant manner. Egg production and feed efficiency were also significantly improved by the 4.05 percent level. Harms and Waldroup (1961) reported two experiments where hens on diets containing 4.60 percent calcium produced eggs with significantly thicker shells without a significant loss in total egg production.

Maintaining Single Comb White Leghorns in cages, Sullivan and Kingan (1962) concluded that a calcium level of 2.80 percent was adequate for maximum egg production, and that higher levels significantly increased egg specific gravity and shell thickness.

Twenty different strains of laying hens were used by Bergdoll (1968) to arrive at his conclusions. The requirements of hens in 80-90 percent production were established at 3.75 percent calcium. Under ideal conditions most commercial flocks would produce at the NRC (1966) recommended level of 2.75 percent, but citing commercial feed companies who used 3.0-3.5 percent in the winter and 3.5-4.0 percent in the summer, a need for a higher level was indicated. Bergdoll also listed three reasons for increasing the dietary calcium of the ration. 1. The larger the eggs produced, the more calcium required. 2. The higher the egg production, the more calcium required. 3. The smaller the hen and the lower feed intake, the higher the normal calcium level should be. This substantiated conclusions made by Titus (1958) from his studies, that the more hens lay the more they consume, and one should feed calcium to meet the requirements of the highest producers.

RELATIONSHIP OF CALCIUM WITH PHOSPHORUS

Most experimenters agreed that after onset of production little regard need be given to the Ca:P ratio in formulating laying rations. Singsen (1966) used ratios of 11.2:1 and 15.0:1 and stated that Ca:P ratio is of relatively little significance in the laying hen, and that the requirement for each mineral should be treated as a single independent need. Scientists have not completely disregarded the effect that raising

either calcium or phosphorus levels has on the other mineral. Reviewing trends in phosphorus, Bird (1960) stated that increasing the level of calcium raised the requirement of phosphorus. Apparently hens do not lay phosphorus deficient eggs, therefore, egg production suffers when a phosphorus deficiency is present. NRC (1962) recommended a phosphorus level of 0.60 percent for mash type rations. Hinners et al., (1963) failed to show any significant changes in shell thickness or hen-day production by increasing phosphorus levels from 0.705 to 1.018 percent total phosphorus for chickens in floor pens. Assuming 50 percent availability, Crowley and associates (1963) used 0.213 percent total phosphorus to produce eggs in floor pens successfully. The same level caused extreme reduction in production of caged layers. Feeding a ration containing 0.41 percent total phosphorus Crowley et al., (1961) were unable to control a rapid decline in shell quality; supplementation in duplicate lots during the experiment slowed the rate of decline, but failed to eliminate it completely. Although no significant difference was reported during the first four months of laying, Evans and associates (1944) showed superior egg production and egg shell thickness at the 0.80 percent phosphorus level over the entire experimental period.

Gillis and associates (1953) results agreed with earlier work which showed that 0.50 percent phosphorus was sufficient if supplied in the most available form. The comparison of the above data was completed using levels of calcium within a range of 2.0 to 3.0 percent.

Harms and co-workers (1965) established the tolerance level of caged layers for phosphorus at 0.80 percent because of the lack of availability to their droppings; a higher level of 1.15 percent total phosphorus depressed egg production significantly. However, Harms et al.,

(1965) referred to their earlier work which stated that 0.60 percent total phosphorus was the highest level that should be fed to caged layers because it was impossible to establish a tolerance level for these birds. During their testing, calcium was maintained at the 3.30 percent level.

Singsen (1966) recommended 0.43 to 0.55 percent total phosphorus for hens at 75 percent production upon the assumption that phytin phosphorus was 50 percent available to laying hens; however, the National Research Council (1966) recommended that 30 percent of total plant phosphorus was available to adult birds. Earlier Singsen et al., (1962) found no significant difference between experimental levels of 0.40, 0.50 and 0.60 percent total phosphorus on egg production for a floor type operation, when the calcium level was maintained at 2.25 percent.

Walter and Aitken (1962) confined White Leghorn pullets to individual cages for a period of 308 days and confirmed reports that 0.70 percent total phosphorus significantly lowered total egg production. They concluded that a level of 0.50 percent total phosphorus was ideal for production, feed efficiency, egg weight, and specific gravity of eggs.

Several researchers desired to establish the efficiency of available phosphorus in various feed grade phosphates (Damron et al., 1967; Dilworth and Day, 1964; Gerry et al., 1949). Dilworth and Day, (1964) maintaining phytin phosphorus constant for all treatments, studied sodium acid phosphate, beta-tricalcium phosphate, and several feed grades of low flourine phosphates when compared to a standard dicalcium phosphate. Sodium acid phosphate was found to be 47 percent as available as dicalcium phosphate and was the highest reported. They also concluded that changes in the Ca:P ratio did not influence availability. Gerry

et al., (1949) compared raw rock phosphate with steamed bone meal at the level of 0.64 percent and reported no significant difference in production and egg weight during a five-month period.

FACTORS EFFECTING EGG SHELL QUALITY

Although mineral effects on shell quality were of the greatest concern in this report, some discussion should consider the evaluation of other factors which may influence shell quality. Reviewing the egg industry's major problems pertaining to shell quality Peterson (1965) described improvements in genetics, nutrition, and management as promoters of most shell weaknesses. Rate of lay exceeding 70 percent over an extended period of time (14-16 months) contribute to the problems of maintaining production and shell quality. Authorities generally accept that modern nutritional knowledge will sustain shell quality for the first half of the laying period, but a decline in shell quality will be seen during the second half of the laying period (Bergdoll, 1968; Durham et al., 1960; Peterson, 1965).

The influence of seasons and age of hens on egg weight, shell thickness, and interior quality was described extensively by Meuller et al., (1960). Although this study was conducted for a longer period than normal productive life, it clearly showed the trend for thinner shells and decline in egg shell quality with increased age and warmer weather. Leong (1963) stated that decline in specific gravity of the egg was related to environmental temperatures and the advanced age of the hen. Review of early reports showed that constant exposure to high temperatures depresses egg shell quality and egg weight (Clark, 1940; Godfrey and Jaap, 1949; Leong, 1963).

For caged pullets the addition of sodium bicarbonate to either feed or water resulted in significant increases in egg production and egg shell quality (specific gravity and thickness measurements) at $P < 0.01$ in a series of experiments by Howes (1966).

Shell formation is extremely complex and many factors are not completely understood; however, nutrition, management, and genetics provide the major influence on research pertaining to shell formation today (Peterson, 1965).

FACTORS EFFECTING EGG PRODUCTION

Temperature extremes, age of bird, and type of bird are a few of the variables which influence total egg production (Clark, 1940). Management techniques such as area, type of feeding, and water availability could also adversely affect egg production (Peterson, 1965).

SPECIFIC GRAVITY AND ITS RELATIONSHIP TO SHELL QUALITY

Marks and Kinney (1964) discussed the relationship between specific gravity, shell thickness, and percent shell when utilized to measure the same trait. Values obtained by these workers provided a highly positive correlation between these measurements. Observations made in this study were in close correlation with values reported earlier by Godfrey and Jaap (1949). This early test resulted in the recommendation to breeders and hatcherymen to use shell weight loss or specific gravity as a guide to improve hatchability and resistance to breakage. Of these three methods, specific gravity was cited as the most efficient procedure.

A method of determining specific gravity was described by Leong (1963) for measuring shell quality without injury to the intact egg.

Specific gravity tests utilize salt solutions and is a floatation procedure, the end point is reached when an egg floats. A higher specific gravity indicates a thicker shell. Leong also reviewed a procedure recommended by Olsson whose solutions ranged from 1.062 to 1.102 at intervals of .004.

Leong (1963) also described the advantages and disadvantages of specific gravity for shell thickness measurement.

Specific gravity utilizes the intact shell egg, which enables the experimenter to use the egg for further experimentation. However, a change in the temperature of the solution or the egg will influence the reading for a particular egg. The number of eggs dipped at a time, the shape of the egg, and possibly of carry-over from each solution complicates the results of this procedure.

Even with the experimental problems associated with the measurement, authorities still recognize the validity of specific gravity as one of the most accurate manual measurements of egg shell thickness (Balloun and Marion, 1962; Godfrey and Jaap, 1949; Marks and Kinney, 1964; Pepper et al., 1961; Walter and Aitken, 1962).

METHODS AND PROCEDURES

A ration containing all major ingredients except the calcium and phosphorus supplements was mixed by the Kansas State University Department of Grain Science and Industry's feed mill and delivered in 50 pound sacks. Calcium and phosphorus were added in the form of calcium carbonate and dicalcium phosphate, and mixed in a 100 pound horizontal mixer for five minutes. All calcium carbonate and dicalcium phosphate were purchased prior to the start of the experiment to eliminate product variability.

The initial weighing of the feed was in pounds but was converted to kilograms for experimental calculations.

Isonitrogenous and isocaloric diets containing 16 percent protein were fed *ad libitum* in cylindrical self-feeders for each of 10 treatments. Masonry sand was added with the mineral supplement to maintain the protein and energy levels constant for each treatment. Tabulated values for each of the 10 treatments are shown in Table 1. Calcium levels of 2.75, 3.00, 3.50, and 4.00 percent were combined with phosphorus levels of 0.60, 0.70, 0.80, and 0.90 percent of the ration. Water was supplied automatically *ad libitum*.

Groups of 77 inbred strain-cross pullets (Hyline 934-E) were assigned randomly to each of 10 treatments. When the pullets had reached 10 percent egg production, the study was started on October 16, 1967. The pullets were housed at the T. B. Avery Poultry Research Center in a clear span poultry house 40' x 100'.

Records were maintained for ten 28-day periods for total egg production, percent production on a hen-day basis, egg weight, and egg specific gravity. Feed consumption and feed efficiency were calculated for four unequal periods. Total feed consumption was recorded in kilograms and feed efficiency in kilograms per dozen eggs produced. Data for total feed consumption and feed efficiency are shown in Tables 2 and 3, respectively.

Collection of eggs was for three consecutive days beginning with the final day of the preceding period. Twelve eggs were saved from trap-nested individuals and marked with the badge number, date, and treatment number. Ten uniform eggs were selected for each treatment and each day for weighing and testing for specific gravity.

Table 1. Composition of Diets Containing Various Levels of Calcium and Phosphorus[1]

Ingredients (Kg)	Treatments									
	1	2	3	4	5	6	7	8	9	10
Corn, yellow, ground	14.98	14.98	14.98	14.98	14.98	14.98	14.98	14.98	14.98	14.98
Sorghum grain, ground	14.76	14.76	14.76	14.76	14.76	14.76	14.76	14.76	14.76	14.76
Alfalfa meal, 17% protein	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14
Soybean meal, 44% solvent extracted	8.63	8.63	8.63	8.63	8.63	8.63	8.63	8.63	8.63	8.63
Salt	.23	.23	.23	.23	.23	.23	.23	.23	.23	.23
Dicalcium phosphate	.34	.34	1.02	1.36	1.02	1.36	1.59	1.02	1.36	1.59
Calcium carbonate	2.72	3.06	2.84	2.61	3.52	3.18	3.06	4.09	3.86	3.75
Sand, masonary	2.16	1.82	1.82	1.70	1.14	1.14	1.02	.57	.45	.34
Calculated composition (%)										
Calcium, %	2.75	3.00	3.00	3.00	3.50	3.50	3.50	4.00	4.00	4.00
Phosphorus, %	0.60	0.60	0.70	0.80	0.70	0.80	0.90	0.70	0.80	0.90
Protein, %	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
Productive energy (Cal/Kg.)	1975	1975	1975	1975	1975	1975	1975	1975	1975	1975

Added equally per treatment:

Trace mineral premix...............23 grams
Vitamin A (10,000 U.S.P./gm.).......15 grams
Vitamin D-3 (15,000 I.C.U./gm.)......4 grams

B-complex vitamin mix.........23 grams
Vitamin B-12 (20 mg./lb.)......12 grams
Methionine....................35 grams

[1]Calculated according to NOPCO Feed Ingredient Analysis Table (1967).

Table 2. Summary of Total Feed Consumption Listed for Each of Four Periods

	Period[1]			
Treatment	1	2	3	4
1.	790.12	575.84	505.31	824.55
2.	793.14	555.85	520.09	803.70
3.	748.67	547.81	499.56	803.54
4.	743.80	552.81	523.39	624.97
5.	793.59	553.39	447.51	730.23
6.	792.90	534.15	493.36	728.97
7.	837.70	560.93	520.43	703.10
8.	793.60	554.57	520.98	802.81
9.	767.89	599.21	503.18	776.00
10.	795.44	578.19	520.84	826.95

[1]Each period was not of equal length; therefore, results were not comparable except for values within the same period. Values were calculated to the nearest 0.01 kilogram.

Table 3. Feed Consumed Per Dozen Eggs Produced

Treatment	Periods 1	2	3	4
	Kg.	Kg.	Kg.	Kg.
1.	2.28	2.20	1.92	2.20
2.	2.28	2.18	2.07	2.17
3.	2.04	1.93	1.80	2.07
4.	2.03	2.04	2.00	1.73
5.	2.30	2.04	1.70	2.02
6.	2.33	2.20	1.89	2.02
7.	2.23	2.14	2.02	1.87
8.	2.34	2.07	1.92	2.06
9.	2.06	2.31	2.00	2.05
10.	2.29	2.12	1.92	2.10

The solutions recommended by Kansas State University for specific gravity was recorded in Table 4. The eggs were first weighed to the nearest 0.01 gram, and then shell quality determined by specific gravity. Specific gravity and egg weight were totaled for all three days and averaged to obtain a representative value for the period. Egg specific gravity was recorded in code by treatment and period as shown in Table 5. Egg weight was tabulated in grams which is presented in Table 6. All reference to specific gravity in this report was recorded in code.

Table 4. Specific Gravity Solutions Used[1]

Code Number	Specific Gravity	Grams NaCl/3 liters	Approximate % NaCl
0	1.060	276	
1	1.065	298	
2	1.070	320	10
3	1.075	342	
4	1.080	365	
5	1.085	390	12
6	1.090	414	
7	1.095	438	
8	1.100	462	14
9	1.105	486	

[1]All reference to specific gravity was recorded using the code number.

EXPERIMENTAL RESULTS

Statistical analysis was by analysis of variance using the two-way classification (Fryer, 1966) both for treatments and periods. Variation between different experimental treatments was the principle consideration of this report; therefore, Fisher's L.S.D. method was used to determine the amount of variation and the ranking of individual treatments. As shown in Table 8, lots underscored by the same line were not significantly different at the level indicated, and any lots not underscored by the same line were significantly different.

Specific Gravity. Analysis of specific gravity data presented in Table 8 indicated there was a significant difference due to treatment

Table 5. Specific Gravity Values in Code for Each Experimental Treatment.

	Periods									
Treatment	1	2	3	4	5	6	7	8	9	10
1.	5.63	5.63	5.50	5.57	4.90	4.70	3.73	4.03	4.50	3.17
2.	5.93	5.77	5.37	5.37	5.10	4.63	4.10	4.37	4.40	3.67
3.	6.00	5.50	5.53	5.43	4.66	4.46	3.73	4.33	4.27	3.37
4.	5.70	5.47	5.20	5.27	4.56	4.43	3.80	4.30	4.20	2.80
5.	5.87	5.60	5.43	5.33	4.76	4.76	3.40	4.33	4.40	3.23
6.	5.70	5.53	5.07	5.07	4.80	4.50	3.20	4.03	4.23	2.97
7.	5.73	5.70	5.30	5.23	4.90	4.33	3.23	3.97	4.13	3.07
8.	5.93	5.70	5.53	5.37	4.96	4.66	3.73	4.40	4.40	3.40
9.	5.77	5.47	5.27	5.47	4.90	4.30	3.43	4.23	4.23	3.10
10.	5.50	5.87	5.30	5.13	4.56	4.30	3.53	3.93	4.43	2.93

Table 6. Egg Weights Calculated by Treatment for Each Experimental Period[1]

Treatment	Periods									
	1	2	3	4	5	6	7	8	9	10
1.	53.95	57.03	60.64	60.61	61.45	62.08	63.38	64.42	63.75	63.63
2.	54.74	57.28	60.71	61.40	61.14	63.33	64.65	65.69	64.21	63.94
3.	52.64	56.10	60.33	61.05	61.76	62.49	62.48	64.12	63.28	63.03
4.	54.32	56.66	59.75	60.80	61.75	64.06	64.27	65.30	64.30	63.74
5.	53.63	57.07	60.00	59.17	62.63	61.35	63.23	62.72	65.02	63.76
6.	54.42	57.72	60.55	59.57	60.58	62.81	63.08	64.83	63.85	62.04
7.	54.90	58.07	62.27	63.15	62.60	63.26	64.57	65.28	64.12	65.69
8.	54.12	57.62	61.04	60.56	60.72	62.32	63.84	64.17	64.75	64.00
9.	55.09	56.87	62.66	62.31	63.12	63.24	65.08	65.14	64.40	63.85
10.	54.63	57.30	61.10	59.92	62.91	63.26	65.72	64.48	65.97	65.14

[1]Weights were calculated to the nearest 0.01 grams.

Table 7. Percent Production Calculated on a Hen-Day Basis for Each Treatment

	Periods									
Treatment	1	2	3	4	5	6	7	8	9	10
1.	56.00	55.26	74.03	71.63	75.38	74.01	74.53	74.81	68.56	68.14
2.	52.77	64.56	73.92	74.30	69.55	69.17	73.03	75.00	70.89	69.91
3.	54.38	67.51	78.57	78.98	78.71	77.60	76.62	74.95	71.38	69.34
4.	54.28	68.23	74.09	76.29	78.43	76.90	73.04	74.68	71.63	68.35
5.	55.54	59.33	74.05	72.56	74.95	74.16	75.86	73.54	67.37	68.63
6.	47.05	63.04	74.62	74.53	74.53	74.25	73.03	72.41	70.22	65.83
7.	60.58	68.78	77.18	73.33	72.77	74.05	73.10	74.62	72.10	68.66
8.	50.40	64.53	75.09	73.84	75.19	75.61	77.02	77.16	72.84	71.03
9.	59.51	66.47	77.28	72.89	74.52	75.71	67.76	76.62	69.35	72.71
10.	49.18	63.74	79.27	78.01	73.56	77.04	74.17	75.42	73.74	71.43

variation. Eggs from 3.00 percent dietary calcium with 0.60 percent dietary phosphorus showed significantly greater specific gravity readings than those of the other levels except treatment 8 (4.00% calcium and 0.70% phosphorus). The analysis of variance for specific gravity showed that period and treatment were highly significant ($P < 0.01$). Graphical comparison plotting phosphorus against specific gravity indicated a decline in specific gravity as dietary calcium and available phosphorus increased (Figure 1).

Table 8. Analysis of Variance for Specific Gravity

Source of Variation	D.F.	Sum of Squares	Mean Squares	F-ratio
Treatment	9	1.34	.15	6.90**
Period	9	68.39	7.60	----**[1]
Treatment x Period	81	1.75	.02	0.00
Total	99	71.47		

Ranked treatments based on Fisher's L.S.D. method for specific gravity.[2]

Ranked treatments:	2	8	1	3	5	9	4	7	10	6
Treatment mean:	4.87	4.81	4.74	4.73	4.71	4.62	4.57	4.56	4.54	4.51

** Significant difference at the 1% level.

[1] An extremely large figure.

[2] L.S.D. was .13 at 5% level of probability. Any two lots not underscored by the same line are significantly different at 5%.

Combination of 4.00 percent dietary calcium with 0.70 percent available phosphorus produced a specific gravity of eggs tested which was not signi-

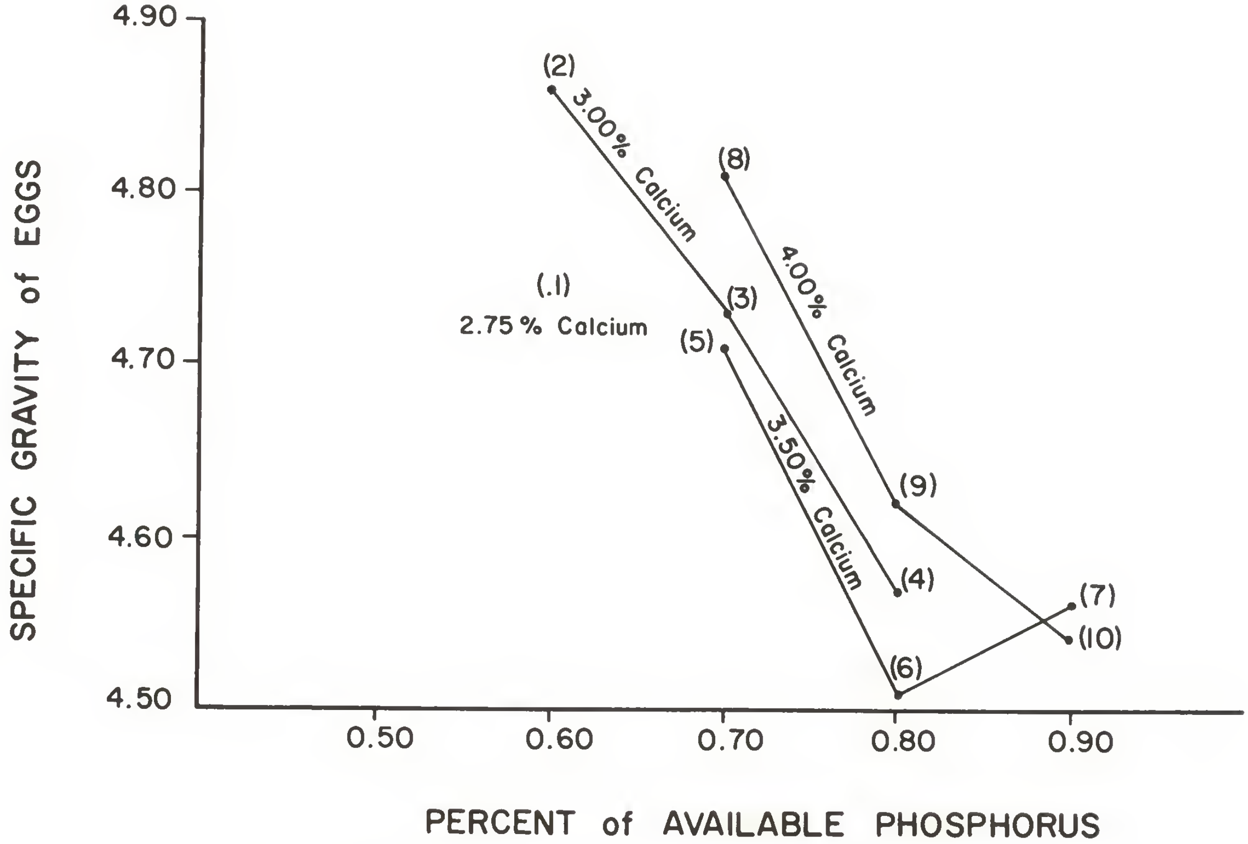

Figure 1. Phosphorus plotted against specific gravity of eggs for specific calcium levels treatment numbers are indicated.

ficantly different from treatment 2 (3.00% calcium and 0.60% phosphorus). The value obtained from treatment 2 was higher, however, than that of treatment 8. All other treatments were significantly different at $P < 0.05$ when compared with treatment 2; however, treatment 3 (3.00% calcium and 0.70% phosphorus) was not significantly different from treatment 8, and the numerical difference from treatment 2 was slight.

It was evident that increasing the levels of dietary calcium did not consistently increase egg specific gravity. Treatment 10 (4.00% calcium and 0.90% phosphorus), the highest mineral content studied, was ranked in ninth place by Fisher's L.S.D., while treatment 8 (4.00% calcium and 0.70% phosphorus) was in the second ranking ($P < 0.05$).

Egg Weight. Evidence produced from the analysis of variance of egg weight (Table 9) showed highly significant results for this particular variable. Greater egg weight was obtained from the higher calcium level associated with higher levels of available phosphorus. The results were not consistent when indicating the combination of minerals essential for maximum egg weight, but the values shown graphically (Figure 2) indicated the higher levels of both mineral supplementation resulted in heavier eggs. Treatment combinations close to the ratio supplied by treatment 2 produced the highest egg weights.

Egg Production. Analysis of variance for egg production was conducted for total egg production and percent production on a hen-day basis (Tables 10 and 11). Percent hen-day production was highly significant for treatments; however, it was low for the production type layer utilized for this experiment. Treatment 3 (3.00% calcium and 0.70% phosphorus) resulted in the highest egg production under both methods analyzed. There was no significant difference between treatment 3 and treatment 10 for both methods.

Table 9. Analysis of Variance for Egg Weight

Source of Variation	D.F.	Sum of Squares	Mean Squares	F-ratio
Treatment	9	30.78	3.42	6.94**
Period	9	1037.58	115.42	----**[1]
Treatment x Period	81	39.91	0.49	0.00
Total	99	1108.24		

Ranked lots based on Fisher's L.S.D. method for egg weight.[2]

Ranked treatments	7	9	10	2	4	8	1	6	5	3
Treatment mean:	62.39	62.18	62.04	61.66	61.50	61.31	61.09	60.95	60.86	60.73

** Significant difference at the 1% level.

[1]An extremely large figure.

[2]L.S.D. was 0.64 at 5% level of probability. Any two lots not underscored by the same line are significantly different at the 5% level.

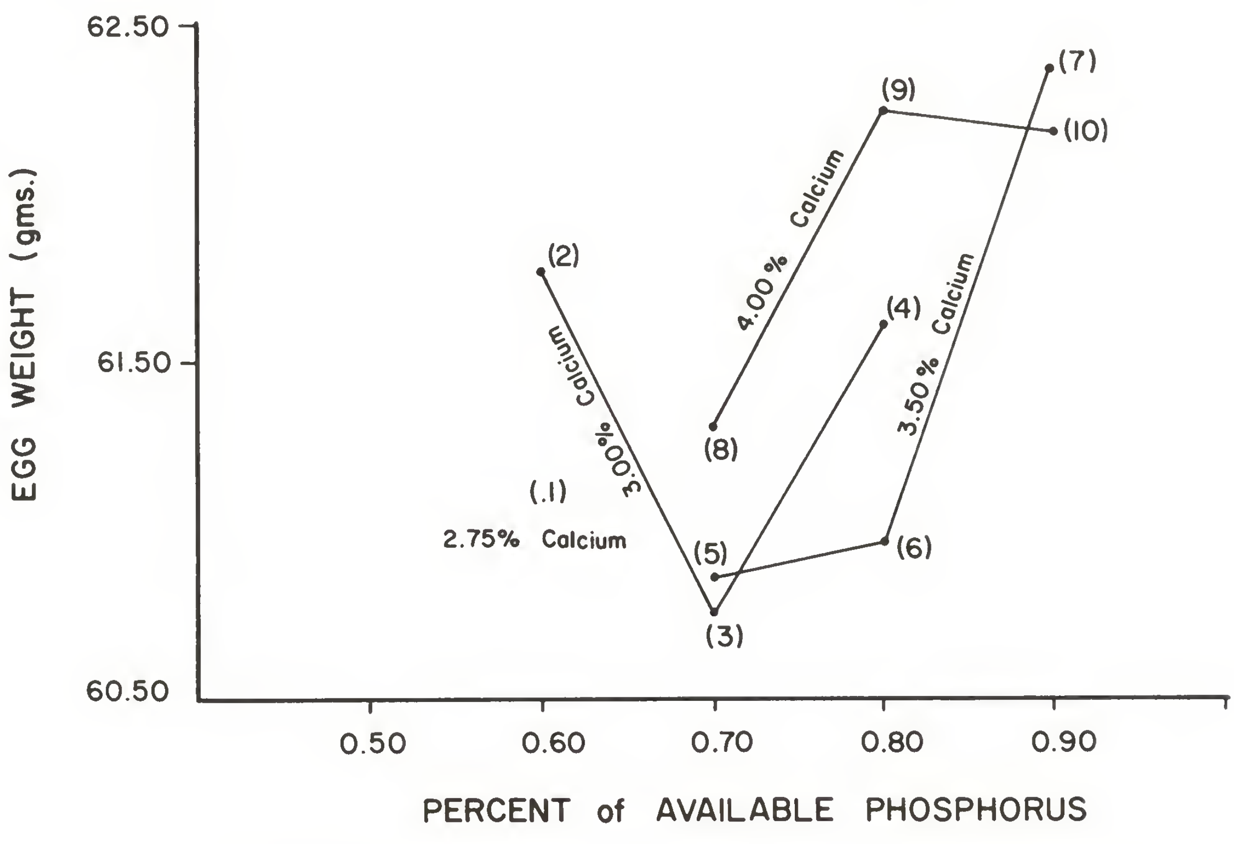

Figure 2. Phosphorus plotted against egg weight for specific calcium levels treatment numbers are indicated.

Percent production on a hen-day basis showed a higher and more consistent production for treatment 3 and 10 throughout the entire experiment (Table 7). Treatments 3, 4, 7, 8, 9, and 10 showed comparable hen-day production, and were not significantly different. Higher levels of dietary calcium fed with higher levels of available phosphorus supported higher levels of production (hen-day) than the lower levels of 3.00 and 2.75 percent calcium fed at the 0.60 percent level of available phosphorus. Decline in production during the last months of the experiment was not as severe as with the lower levels of minerals.

Treatments 1, 2, 5, and 6 dropped sharply in production after the eighth period of production (during the warmer months of production).

Feed Consumption and Feed Efficiency. Feed consumption when analyzed was not significantly different among treatments, but was highly significantly different among periods (Table 12).

Feed efficiency was also not significantly different among treatments, but was highly significantly different among periods (Table 13).

Analysis of variance indicated a highly significant difference between rations 1 and 2 when compared with rations 3 and 4. Higher levels of available phosphorus fed with lower levels of calcium generally depressed feed efficiency; however, this trend was not apparent from the data obtained for total feed consumption. Treatment 3 supported the best feed efficiency and best feed consumption, while maintaining the best performance on a hen-day basis.

Table 10. Analysis of Variance for Total Egg Production

Source of Variation	D.F.	Sum of Squares	Mean Squares	F-ratio
Treatment	9	104205	11578	3.25**
Period	9	1412076	156897	44.13**
Treatment x Period	81	288009	3555	0.00
Total	99	1804291		

Ranked lots based on Fisher's L.S.D. method for total egg production.[1]

Ranked treatments:	3	10	7	8	4	9	1	5	6	2
Treatment mean:	1578	1542	1524	1523	1514	1513	1495	1479	1471	1470

** Significant at the 1% level.

[1] L.S.D. was 53.07 at 5% level of probability. Any two lots not underscored by the same line are significantly different at the 5% level of probability.

Table 11. Analysis of Variance for Percent Production on a Hen-Day Basis.

Source of Variation	D.F.	Sum of Squares	Mean Squares	F-ratio
Treatment	9	156.36	17.37	2.70**
Period	9	4274.15	474.91	73.79**
Treatment x Period	81	521.30	6.44	0.00
Total	99	4951.81		

Ranked lots based on Fisher's L.S.D. method for percent production.

Ranked treatments:	3	4	10	7	9	8	5	2	1	6
Treatment means:	72.80	71.59	71.56	71.52	71.28	71.27	69.90	69.31	69.24	68.95

** Significant at 1% level.

[1]L.S.D. was 2.28 at 5% level of probability. Any two lots not underscored by the same line are significantly different at the 5% level of probability.

Table 12. Analysis of Variance for Total Feed Consumption

Source of Variation	D.F.	Sum of Squares	Mean Squares	F-ratio
Treatment	9	16768	1863	1.42
Period	3	597695	199231	----** [1]
Treatment x Period	27	35371	1310	0.00
Total	39	649835		

Ranked lots based on Fisher's L.S.D. method for feed consumption.[2]

Ranked treatments:	10	1	2	8	9	7	3	6	5	4
Treatment mean:	680.36	673.96	668.20	667.79	661.57	655.54	649.90	637.35	631.18	611.24

** Significant difference at 1% level.

[1] Extremely large figure.

[2] L.S.D. was 52.52 at 5% level of probability. Any two lots not underscored by the same line are significantly different at the 5% level of probability.

Table 13. Analysis of Variance for Feed Efficiency (feed per dozen eggs produced)

Source of Variation	D.F.	Sum of Squares	Mean Squares	F-ratio
Treatment	9	.19431	.02159	1.78
Period	3	.4674	.15582	12.87**
Treatment x Period	27	.32679	.01210	0.00
Total	39	.98856		

Ranked lots based on Fisher's L.S.D. method for feed efficiency.[1]

Ranked treatments:	2	1	10	9	8	6	7	5	3	4
Treatment mean:	2.175	2.150	2.108	2.105	2.098	2.065	2.065	2.035	1.960	1.950

** Significant difference at the 1% level.

[1] L.S.D. was .1596 at the 5% level of probability. Any two lots not underscored by the same line are significantly different at the 5% level of probability.

DISCUSSION

The modern hen with her sensitive capabilities should be able to produce at a high level of production without detrimental effects on egg shell thickness. This ability is correlated with the efficiency of the hen to utilize available minerals (calcium and phosphorus) for construction of an egg with a strong shell. The ability to utilize these minerals is dependent upon the strain of bird, and on the individual characteristics of each particular bird (Quisenberry, 1966).

Although recognition has been given to the characteristics of the chicken, most commercial producers formulate rations to meet the requirements for percent production and shell quality. The amount of calcium and phosphorus has not been established conclusively by various authorities (Berg et al., 1950; Hurwitz and Bar, 1966; Peterson et al., 1960; Singsen, 1966). Establishment by several workers of a specific tolerance level for phosphorus, influenced by the type of housing, provides a basis for this mineral's level within rations (Harms et al., 1965; Walter and Aitken, 1962). However, there was disagreement among researchers' results when the relationship among levels of calcium and phosphorus was considered. Hinners et al., (1963) reported increased shell thickness without significant decline in hen-day production using a calcium level of 6.27 percent and a phosphorus level of 0.705 percent. He also established that increases in phosphorus had no significant difference on these production traits.

The design of this experiment was to provide evidence concerning the effect of increasing levels of calcium fed with increasing levels of available phosphorus. During the experiment four levels of calcium (2.75, 3.00, 3.50, and 4.00%) were fed with various combinations of phosphorus

(0.60, 0.70, 0.80, and 0.90%), and the effects upon the variables of feed consumption, feed efficiency, egg production, egg weight, and egg specific gravity were tested.

Results from testing egg specific gravity indicated maximum shell thickness was attained from treatment 2 (3.00% calcium and 0.60% phosphorus). The greatest response of shell quality to phosphorus seemed to be produced by a phosphorus level of 0.70 percent or lower. Although specific gravity for treatment 2 was highly significantly different as compared with most treatments, it was not significantly different from treatment 8 (4.00% calcium and 0.70% phosphorus). There was no significant difference between treatment 8 and the recorded values for treatments 1, 3, and 5. Evaluating the specific gravity value over the entire length of the experiment, treatment 2 maintained the best specific gravity code value (Table 5). The decline in shell thickness for the final three periods was not as severe for treatment 2 as for the other experimental diets. The coded specific gravity measurements for periods 7 and 10 (Table 5) lack validity because of faulty handling; therefore, emphasis cannot be placed on the analysis of these two periods. However, it may be noted that the eggs of higher specific gravity values produced by hens on experimental diets 2 and 8 withstood mis-handling better than the other treatments.

Upon evaluation of specific gravity, depending upon the calcium level used, a level of 3.00 and 4.00 percent calcium with 0.60-0.70 percent available phosphorus seems to be sufficient to maintain shell quality. Specifically the combinations of 3.00 percent calcium and 0.60 percent phosphorus and 4.00 percent calcium and 0.70 percent phosphorus maintained the best shell quality of the eggs tested. Feeding experimental diets having a

Ca:P ratio of approximately 5:1 produced the highest shell quality value for each experimental block. This conclusion can best be shown by graphic evaluation (Figure 1) of phosphorus levels against specific gravity with an experimental block, containing a level of calcium.

Results from the evaluation of egg weight data (Tables 6 and 9) agreed with Balloun and Marion (1962) and Singsen et al., (1962) in indicating that level of calcium appeared to have no effect on egg weight. No correlation was apparent between eggs with higher specific gravity and treatments with higher egg weights. A decline of egg weight during the warmer months of the study was not seen which was in agreement with Crowley et al., (1961). Although significant differences were found among various treatments, the difference in egg weight were not conclusive enough when considering the phosphorus level of the treatments. Since none of the treatments contained less than the 0.50 percent available phosphorus recommended for maintenance of egg weight (Singsen et al., 1962; Gillis et al., 1953) a decline in egg weight was not expected. Singsen (1962) also recorded no effects on egg weight by higher levels of phosphorus (0.70%). Increases in egg weight would be expected with a decline in egg production, which was not observed during this experiment.

Performance data calculated from total egg production and percent production on a hen-day basis was significant at the $P < 0.01$ level. Comparison of total egg production and percent production showed similar direction; therefore, evaluation was considered on a hen-day basis because of the consideration of mortality. The generally lower percent egg production experienced by treatments 2 and 8 significantly affected the specific gravity of the eggs. Treatments with eggs of higher specific gravity values generally were at lower percent egg production (Tables 8,

10, and 11). Treatment 6 was not included in this discussion because of its position in the analysis.

Referring to percent production tabulated by period (Table 11), treatment 8 maintained a fairly constant production during the entire study, and was not significantly different from Fisher's top ranked treatment. Treatment 2 dropped in percent production during periods 5 and 6, but still was not significantly different from treatment 8. Treatment 3 supported the highest egg production for the entire experiment.

Analysis of variance for the total feed consumption showed no significant difference between treatments except with treatment 10 compared with treatment 4. The decline in consumption could be attributed to the high level of phosphorus (0.80%) which was fed with a low level of calcium (3.00%). Harms et al., (1965) stated the tolerance level for floor layers was 0.80 percent available phosphorus with a constant level of 3.30 percent calcium.

Treatments 3 and 4 supported the best feed efficiency for the entire study, but were significantly different from only treatments 1 and 2 (Table 13). Treatments 2 and 8, with the highest specific gravity values, were not significantly different from each other. Feed efficiency did not establish a trend between the minerals as the other variables of the study. Duplicate lots might have aided in recording a trend for this variable.

SUMMARY AND CONCLUSIONS

This experiment was designed to determine the effects of feeding increasing levels of calcium with increasing levels of available phosphorus on six experimental performance variables (total egg production, percent production on a hen-day basis, egg weight, feed consumption, feed

efficiency, and specific gravity of eggs). The areas of environment, housing, lack of duplicate treatments, and strain of birds were considered the unmeasurable limiting factors of this experiment.

Combinations of mineral supplementation were fed with a basal composed of the NRC (1966) recommended levels of 2.75 percent calcium and 0.60 percent phosphorus. A calcium level of 3.00 percent was fed with phosphorus levels of 0.60, 0.70, and 0.80 percent. The calcium levels of 3.50 and 4.00 percent were fed with available phosphorus levels of 0.70, 0.80, and 0.90 percent.

Information obtained and tabulated from the results of this study provided the basis for the following conclusions. Egg specific gravity was highest for treatments 2 and 8 with treatment 2 being the most significantly different from the other experimental diets. Considering egg specific gravity as a primary measurement of egg shell thickness, the results indicate the mineral levels of 3.00 percent calcium and 0.60 percent phosphorus were sufficient for maintenance of egg shell quality for this particular strain of birds under these experimental conditions. The specific gravity code for treatment 3 was significantly different from treatment 2, but the difference was very slight. Treatment 8 was not significantly different from treatment 2; therefore, because of the higher mineral level it was not economically reasonable for further consideration.

Treatments with the higher mineral produced maximum egg weight; however, treatment 2 was not significantly different from the higher levels fed. Since the data for egg weight did not conclusively indicate a trend of the mineral effects on egg weight, the mineral contents of treatment 3 (3.00% calcium and 0.70% phosphorus) were sufficient for sustaining this performance variable (Table 9).

The feed efficiency and total feed consumption data illustrated the efficiency that was attained by treatments 3 and 4 during the entire experiment. Results from the feed data do not show a relationship between higher levels of minerals and depressed feed consumption reported by previous studies. Treatment 2 had the highest feed consumption and poorest feed efficiency indicating perhaps that the mineral level was not sufficient to meet the requirements for this group's performance. These data also verified to some extent previous authorities' reports that the hen can adjust to meet her mineral requirements (increased intake and reduced egg production). Adjustments were attained during this study by the increased consumption of treatments 1 and 2.

Data for total egg production and percent production on a hen-day basis provided the conclusion that treatment 3 was the mineral level to be fed. Treatment 3 had the highest total egg production and percent production, and was significantly different from treatment 1 for both observations.

The data obtained definitely indicated that the NRC recommended levels for calcium and perhaps phosphorus were inadequate for this strain of commercial layers. Observation of the data by periods suggested that higher levels of calcium and phosphorus should be fed during the last few months of production. Levels of 3.00-3.50 percent calcium would be advisable for warmer months that result in a decreased consumption of feed. Higher phosphorus levels do not seem to be as pertinent as once believed. Some evidence suggested that laying hens should not be fed too wide a Ca:P ratio, as high levels of phosphorus depressed egg production when fed with low levels of calcium (below 3.00%).

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INFLUENCE ON PERFORMANCE OF FEEDING EGG-STRAIN LAYING HENS INCREASING LEVELS OF PHOSPHORUS WITH INCREASING LEVELS OF CALCIUM

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The effects of increasing levels of dietary calcium fed with increasing levels of available phosphorus was evaluated during this experiment. Six experimental performance variables were used as a basis for this determination (total egg production, percent production on a hen-day basis, egg weight, feed consumption, feed efficiency, and specific gravity of eggs). The primary objective of this investigation was to determine which of the experimental levels of calcium and phosphorus supported optimum performance during the study.

Nine experimental treatments were fed and compared with a basal ration composed of the NRC (1966) recommended levels of 2.75 percent calcium and 0.60 percent phosphorus. A calcium level of 3.00 percent was fed with available phosphorus levels of 0.60, 0.70, and 0.80 percent. Two calcium levels of 3.50 and 4.00 percent were fed with variable levels of 0.70, 0.80, and 0.90 percent phosphorus.

Seventy-seven inbred strain-cross pullets were randomly assigned to each of the 10 experimental lots, and remained on the study for ten 28 day periods with egg weight and egg specific gravity data collected for three consecutive days at the end of each experimental period. Feed efficiency and feed consumption were calculated for four unequal periods during the study.

All data were statistically analyzed by two-way analysis of variance for treatment and period. Based on the statistical evaluation of this information, the following conclusions were reached: 1. Shell quality, as measured by egg specific gravity, was significantly different for both period and treatment at the $P < 0.01$ level. The experimental diet with 3.00 percent calcium and 0.60 percent phosphorus obtained the best specific gravity when ranked by Fisher's L.S.D. method for specific gravity;

however, it was not significantly different from the diet containing 4.00 percent calcium and 0.70 percent phosphorus. Support of maximum shell quality was attained by a calcium level between 3.00 and 4.00 percent, but was dependent upon the level of phosphorus fed (0.60 or 0.70 percent). 2. Data obtained for egg weight did not conclusively indicate the effects of increasing mineral levels upon this variable. 3. Maximum feed efficiency and minimum feed consumption was attained by a calcium level of 3.00 percent and phosphorus level of 0.70 percent. 4. Maximum egg production and percent production on a hen-day basis was recorded by levels of 3.00 percent dietary calcium and 0.70 available phosphorus.

From the data described above the following conclusions were formulated. The NRC recommended levels for both minerals were inadequate for optimum performance of this strain of layers. Assumptions based upon analysis of periods suggested that higher levels of calcium should be fed during the warmer periods of the laying cycle. Some evidence indicated that feeding too large a level of phosphorus with a low level of calcium depressed egg production. Calcium levels of 3.00-3.50 percent were recommended for this strain of layers, and a phosphorus level of between 0.60 and 0.70 percent was indicated.